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AN EVALUATION OF VARIOUS VISCOUS CRITERION COMPUTATIONAL ALGORITHMS

by

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ABSTRACT

The viscous criterion (V*C) has been proposed by biomechanics researchers as a generic biomechanical index for potential soft tissue injury. It is defined by the product of the velocity of deformation and the instantaneous compression of torso and abdomen. This criterion requires calculation and differentiation of measured torso/abdomen compression data.

Various computational algorithms for calculating viscous criterion are reviewed and evaluated in this paper. These include methods developed by Wayne State University (WSU), NHTSA (DOT) and Ford. An evaluation has been conducted considering the accuracy of these algorithms with both theoretical and experimental data from dummy rib compressions obtained during a crash test. Based on these results, it is found that:

- V*C results depend on the scheme used in the computation process, the sampling rate and filtering of original raw data.
- The NHTSA method yields the lowest V*C value.
- The WSU method gives about the same, but fluctuating, V*C value as the Ford method.
- The Ford method provides an accurate and smooth V*C result.

It is recommended that the computation method/process should be standardized.

BACKGROUND

The final rule on dynamic side impact test procedure in FMVSS 214 was published by NHTSA on October 30, 1990, which specified that the <u>S</u>ide <u>I</u>mpact <u>D</u>ummy (SID) responses be used as the basis for determining pass/fail criteria. The SID injury criteria are acceleration-based TTI (Thoracic Trauma Index) and pelvic g's. On December 27, 1991, NHTSA issued an ANPRM (<u>A</u>dvanced <u>N</u>otice of <u>P</u>roposed <u>R</u>ule<u>M</u>aking), requesting comments on the desirability and need for specifying alternative dummies to SID. Two dummies being considered by NHTSA as alternative test devices are BioSID and EuroSID-1.

INTRODUCTION

The first EuroSID and BioSID were completed in 1988 and 1989, respectively. BioSID was developed by SAE in cooperation with General Motors (GM), while EuroSID-1 was developed by a group of research organizations under the auspices of the European Experimental Vehicle Committee (EEVC). Both the BioSID and EuroSID-1 are more advanced and biofidelic than the SID [1]*. These two dummies have more instrumentation/measurement capabilities for addressing other injury criteria that are based on force, compression, and velocity. Table I compares the parameters and limits for various injury criteria between SID and BioSID. It should be pointed out that the acceleration-, force-, and compression-based injury criteria can be assessed from direct measurements. The assessment of viscous-based injury criterion, however, requires further calculations based on measured abdomen/chest compression data. Development of stable differentiation algorithms are needed in the process. This paper evaluates the various computational algorithms on viscous criterion.

WHAT IS VISCOUS CRITERION (V*C) ?

V*C or VC represents viscous criterion which is defined by the rate sensitive torso compression as a generic biomechanical index for potential soft tissue

*Numbers in brackets [ ] denote references at the end of this paper.

Table I
INJURY CRITERIA

	FMVSS 214		Alternate Dummies (ANPRM)				
	SID		BioSID		EuroSID-1		
Injury criteria	Parameter	Limits	Parameter	Proposed Limits	Parameter	Proposed* Limits	Remarks
• Acceleration-based					• Head Performance Criterion (HPC)	< 1000	
	• Pelvic accel.	< 130 g	• Pelvic accel.	< 130 g	• Pelvic accel.	< 130 g	• Direct measurement using accelerometers and FIR filtered
	• TTI(d)	< 90 g 2-Dr < 85 g 4-Dr	• TTI(d)	< 90 g 2-Dr < 85 g 4-Dr	• TTI(d)	< 90 g 2-Dr < 85 g 4-Dr	• Calculated based on: TTI(d) = 1/2[max. rib accel + max. T12 accel.] where T12 is measured at the lower spine All accelerations are FIR filtered.
• Force-based	• None		• Forces - pubic symphysis - Iliac wing • Moments	 < 10 kN < 10 kN	• Forces - pubic symphysis - abdomen internal	 < 10 kN < 2.5 kN	• Direct measurement using load cells
• Compression-based	• None		• Displacement - Lat. rib def. - Abdomen comp.	 < 42 mm < 39 mm	• Displacement - Lat. rib def. - Abdomen comp.	 < 42 mm < 39 mm	• Direct measurement using potentiometers
• Viscous-based	• None		• V*C	< 1 m/sec	• V*C	< 1 m/sec	• Calculation requires: - abdomen/chest compression data - differentiation - computation algorithm

Notes:
. A dynamic side impact protection Final Rule was issued on October 30, 1990. A four year phase-in (10%, 25%, 40% and 100%) will apply during the 1994/95/96/97 model years.
. TTI stands for Thoracic Trauma Index.
* Proposed European Side Impact criteria limits.

injury [2] resulting from a frontal or side impact to the chest or abdomen. Let

D(t) = the instantaneous chest (rib) or abdomen deformation along the direction of the applied impact to the torso

and,

V(t) = d[D(t)]/dt, the velocity of deformation.

The time function of VC is formed by the product of the velocity of deformation, V(t), and the instantaneous compression, C(t). Mathematically,

$$VC = V(t)*C(t),$$

where $C(t) = D(t)/D_0$, with D_0 being the initial torso thickness and half the torso width for frontal and side impacts, respectively. It is noted that C(t) is a dimensionless quantity. VC, therefore, has the same dimension as V(t) expressed in terms of either m/s or mph.

The procedure for computing VC is schematically shown in Figure 1. The maximum risk of soft tissue injury associated with a specific impact-induced viscous response VC occurs at the peak viscous response $[VC]_{max}$. The viscous tolerance of $[VC]_{max}$ = 1 m/s is being proposed by biomechanics researchers as the threshold of soft tissue injury [2].

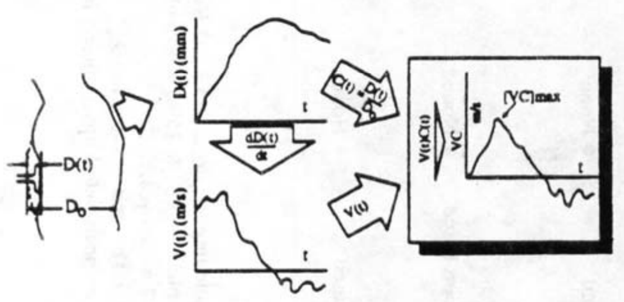


Figure 1: Procedure for computing VC

REVIEW OF VARIOUS COMPUTATIONAL SCHEMES

The procedure for computing VC as shown in Figure 1 appears to be straightforward and simple. However, several approaches can be taken in processing and differentiating the deformation data. Due to slight variations in these approaches, the results of one procedure may be considerably different than the results of another, even though the same deformation data are used as inputs to the process. The following organizations have developed individualized methods for computing VC.

- GM
- NHTSA (DOT)
- Wayne State University (WSU)
- Ford (Alpha)

A review of the various computational schemes follows:

- GM method:

The procedure [2] for the GM method is illustrated in Figure 2. The "chest deflection" data are digitized first at a rate of 10,000 points per second to yield the chest deformation data, D(t). A central difference scheme is used to differentiate the chest deformation data. The result from differentiation is further filtered using SAE60 class filter to give the velocity of deformation. Dividing the chest deformation by D_0 and multiplying the velocity of deformation yield the viscous response time function VC.

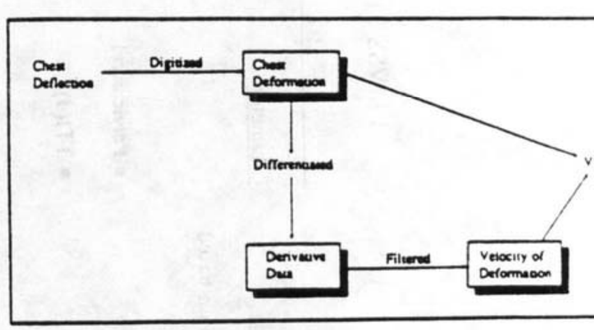


Figure 2: Scheme for GM method

- NHTSA method:

The approach taken by NHTSA is shown in Fig. 3.

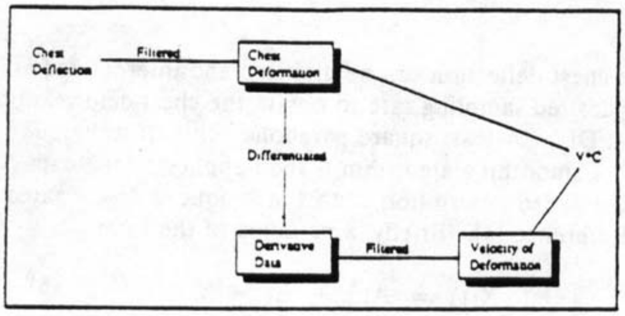


Figure 3: NHTSA Method

In this method, the "chest deflection" data are filtered with a Butterworth filter to give the chest deformation, $D(t)$. The chest deformation is then differentiated by taking the derivative of the 4-th-degree interpolating polynomial with the following numerical scheme [3]:

The 4-th-degree interpolating polynomial is expressed as:

$$P_4(t) = f(t_0) + (t - t_0)\frac{\Delta f(t_0)}{\Delta t} + \cdots$$

$$+ (t - t_0)(t - t_1)(t - t_2)(t - t_3)\frac{\Delta^4 f(t_0)}{(\Delta t)^4 4!} \qquad (1)$$

then, the derivative of $P_4(t)$ with respect to t is given by

$$\frac{dP_4(t)}{dt} = \frac{\Delta f(t_0)}{\Delta t} + (2t - t_0 - t_1)\frac{\Delta^2 f(t_0)}{2!\,(\Delta t)^2}$$

$$+ [3t^2 - 2(t_0 + t_1 + t_2)t$$

$$+ (t_0 t_1 + t_0 t_2 + t_1 t_2)]\frac{\Delta^3 f(t_0)}{3!\,(\Delta t)^3}$$

$$+ [\,4t^3 - 3t^2(t_0 + t_1 + t_2 + t_3)$$

$$+ 2t(t_0 t_1 + t_0 t_2 + t_0 t_3 + t_1 t_2 + t_1 t_3 + t_2 t_3)$$

$$- (t_0 t_1 t_2 + t_0 t_1 t_3 + t_0 t_2 t_3 + t_1 t_2 t_3)]\frac{\Delta^4 f(t_0)}{4!\,(\Delta t)^4}$$

(2)

The derivative data are again filtered to provide the velocity of deformation.

The VC time function is then obtained by dividing the chest deformation by D_0 while multiplying the velocity of deformation.

- WSU Method:

A schematic of the WSU method is shown in Figure 4. This method allows the chest deflection data to be smoothed prior to filtration. The smoothed and unsmoothed data are filtered using an SAE180 class filter to give the chest deformation, $D(t)$. The chest deformation data are then fitted by the Lagrange's interpolating polynomial [4] as follow:

$$p_2(t) = \frac{(t-t_1)(t-t_2)}{(t_0-t_1)(t_0-t_2)} f(t_0) + \frac{(t-t_0)(t-t_2)}{(t_1-t_0)(t_1-t_2)} f(t_1) + \frac{(t-t_0)(t-t_1)}{(t_2-t_0)(t_2-t_1)} f(t_2) \qquad (3)$$

Differentiating Eq. (3) with respect to t yields the velocity of deformation:

$$\frac{dp_2(t)}{dt} = \frac{(2t-t_1-t_2)}{(t_0-t_1)(t_0-t_2)} f(t_0) + \frac{(2t-t_0-t_2)}{(t_1-t_0)(t_1-t_2)} f(t_1) + \frac{(2t-t_0-t_1)}{(t_2-t_0)(t_2-t_1)} f(t_2) \qquad (4)$$

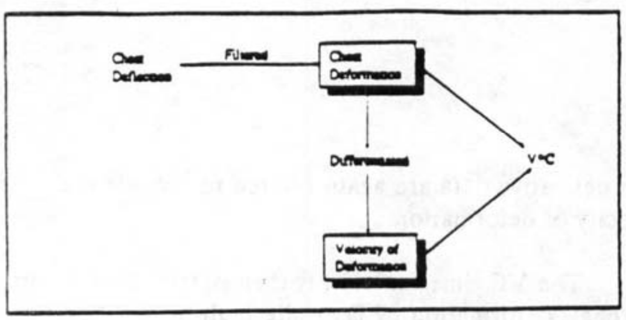


Figure 4: WSU Method

- <u>Ford Method:</u>

This method was developed by the Body Engineering Department, Alpha Simultaneous Engineering of Ford Motor Company. The procedure for calculating VC is demonstrated in Figure 5.

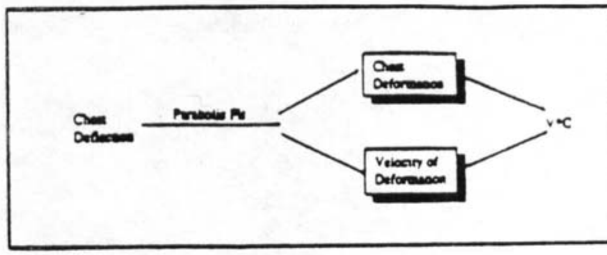


Figure 5: Ford Method

The chest deflection can be digitized and interpolated at any desired sampling rate to obtain the chest deformation data, D(t). A least square parabolic curve fit technique with a smoothing algorithm is then applied to the data. The detailed description of this technique is documented in Reference [5]. Briefly, a parabola of the form

$$X(t) = At^2 + Bt + C \qquad (5)$$

is used to fit the chest deformation data within a sliding window in time domain. Constants A, B, and C are determined in a least-squared sense by setting the time at the mid-point of a sliding window of size 2n to zero. This leads to determination of constants A, B, and C as follows:

$$A = \frac{(2n+1)\sum_{i=-n}^{n} X_i t_i^2 - K_2 \sum_{i=-n}^{n} X_i}{(2n+1)K_4 - K_2^2} \qquad (6)$$

$$B = \frac{\sum_{i=-n}^{n} X_i t_i}{K_2} \qquad (7)$$

$$C = \frac{K_4 \sum_{i=-n}^{n} X_i - K_2 \sum_{i=-n}^{n} X_i t_i^2}{(2n+1)K_4 - K_2^2} \qquad (8)$$

where $K_2 = \sum_{i=-n}^{n} t_i^2$ and $K_4 = \sum_{i=-n}^{n} t_i^4$

The velocity of deformation can be obtained by differentiating Eq. (5) with respect to t and by substituting t = 0. This leads to:

$$V = B = \frac{\sum_{i=-n}^{n} X_i t_i}{K_2} \qquad (9)$$

Also, note that X(0) = C is the value of the fitted parabola, which is used for the chest deformation data.

Based on the above discussions, procedures for computing VC in the order of increasing complexity are:

- Ford method
- WSU and GM methods
- NHTSA method.

Next, the accuracy in the velocity of deformation needs to be evaluated and assessed. Since the computer program for the GM method is not available to Ford, the GM method will be excluded from the evaluation.

DETERMINATION OF ACCURACY IN THE VELOCITY of DEFORMATION

A procedure for determining the accuracy in the velocity of deformation is shown in Figure 6. The velocity of deformation from each method is integrated to obtain the "integrated" chest deformation data, which are then compared with the original chest deformation data.

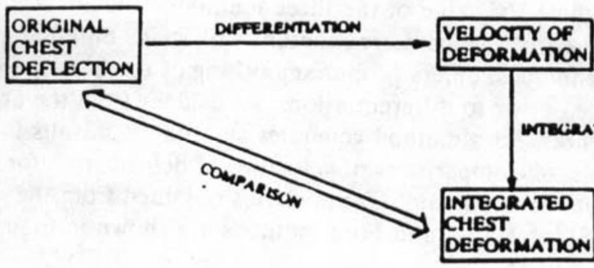


Figure 6: A procedure for determining the accuracy in the velocity of deformation

The accuracy of the velocity of deformation is determined by the degree of correlation between the original chest deformation and that obtained from integration. Any significant discrepancy between the "integrated" vs. the original chest deformation data is indicative of "loss of information" or inaccuracy introduced by the algorithm being tested. The "loss of information" may be due to over-filtering of data or inaccuracy in the numerical solution of the algorithm. An assessment of the accuracy in the velocity of the deformation is made by the following two approaches:

- Using Analytically Generated Hypothetical Data:

A set of analytical data is generated from a periodic multi-sine function:

$$X_m(t) = \sum_{i=1}^{m} A_i \cos(\omega_i t + \phi_i) \qquad (10)$$

where m is the number of harmonics, ω_i are the angular frequencies, and ϕ_i are the phase angles. A displacement-time history obtained from Eq.(10) using 31 harmonics is shown in Figure 7 and will be treated as an analytically generated chest deformation.

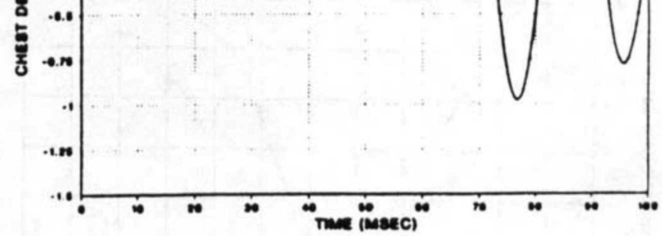


Figure 7: A multi-sine function for chest deflection (an analytically generated data)

Differentiation of $X_m(t)$ yields the velocity of deformation given by the expression:

$$V_m(t) = \sum_{i=1}^{m} A_i \, \omega_i \sin(\omega_i t + \phi_i) \qquad (11)$$

The time history of $V_m(t)$ is shown in Figure 8. VC time function is then formed according to the scheme previously described.

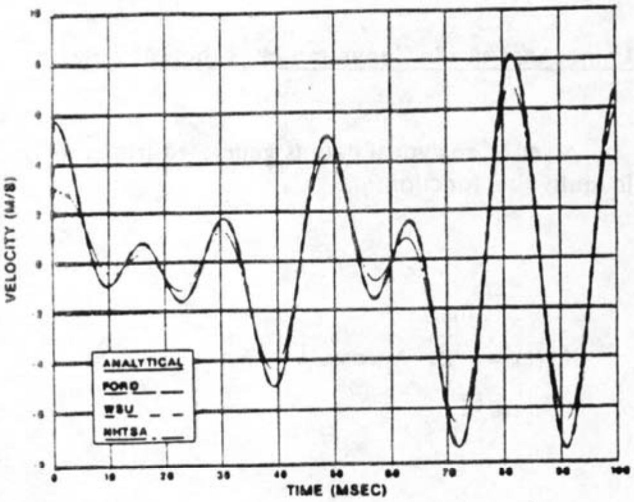


Figure 8: The time history of velocity of deformation (an analytically generated data)

- Using Experimental Data from BioSID's Rib:

A side impact test was conducted at 33.5 mph with a 27-degree crabbed Moving Deformable Barrier (MDB). BioSIDs with arms down were seated in the driver and the left rear positions. Both the front and rear seated BioSIDs' upper rib data from this test, shown in Figures 9 and 10, were used in the evaluation of various VC algorithms.

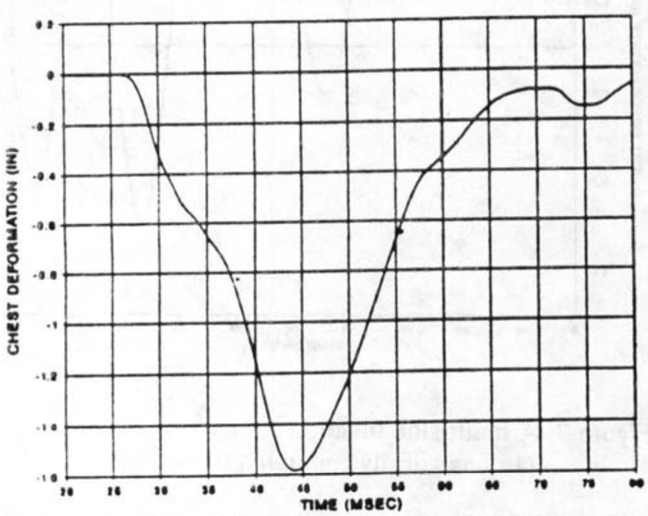


Figure 9: Driver BioSID's upper rib deflection

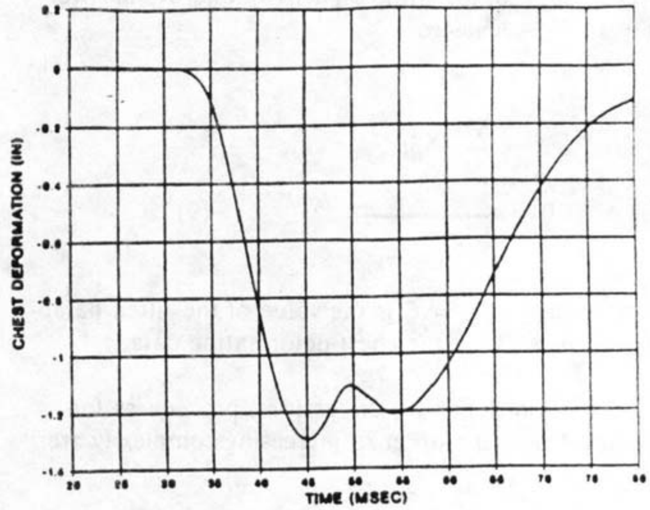


Figure 10: Rear seated BioSID's upper rib deflection

DISCUSSION OF RESULTS FROM EVALUATION OF ALGORITHMS

Time functions of viscous criterion for the analytical data and the upper rib data from both the front and rear seated dummies are computed by the WSU, NHTSA, and Ford methods. Results are presented in Figures 11 through 13.

Examination of Figures 11 through 13 reveals that VC results are computational scheme dependent. The NHTSA method yields the lowest VC value among the three methods. This is probably due to over filtration in the computation process. The WSU method yields better accuracy in the hypothetical velocity of deformation time history than with those obtained from experimental data. When hypothetical data are analyzed, the WSU method provides the same results as with the Ford method. However, the WSU method generates fluctuations in the velocity of deformation time history, thus yielding the highest VC value of the three methods. Fluctuations in the derivative data are inherent with many differentiation techniques, unless proper smoothing of the data is applied prior to differentiation. As evident from the above figures, Ford method generates smooth VC results in all cases. Comparisons of velocities of deformation for the front and rear BioSID upper ribs obtained from the WSU, NHTSA and Ford methods are shown in Figures 14 and 15.

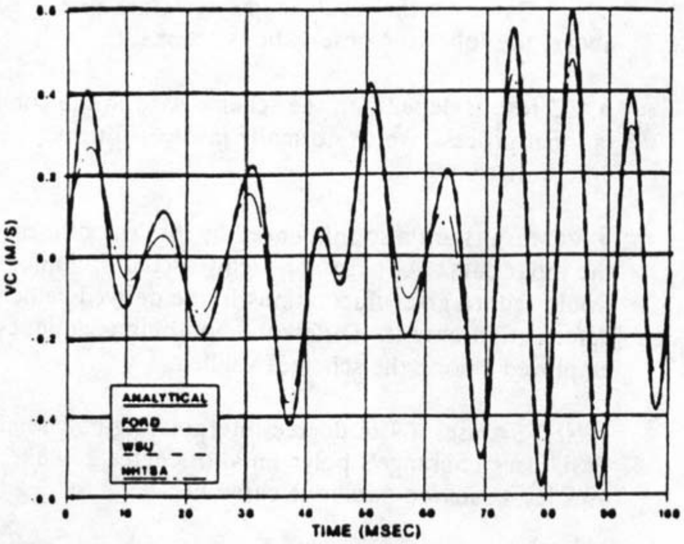


Figure 11: Results of VC from WSU, NHTSA and Ford methods

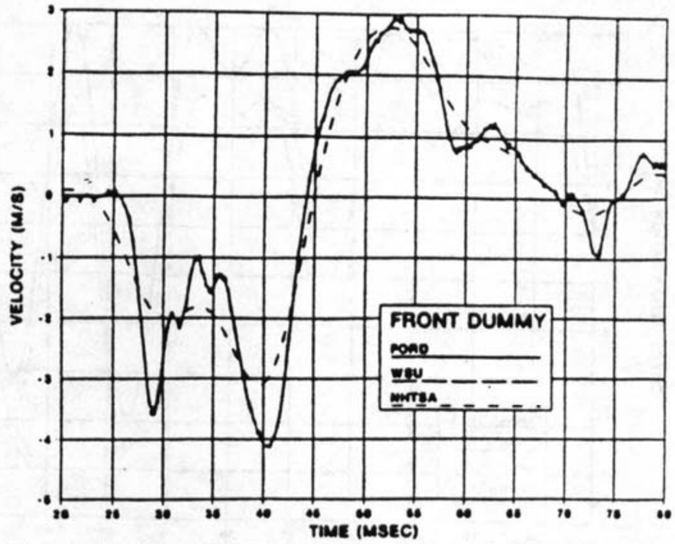


Figure 14: Comparisons of velocities of deformation among WSU, NHTSA, and Ford methods - Front seated dummy upper rib

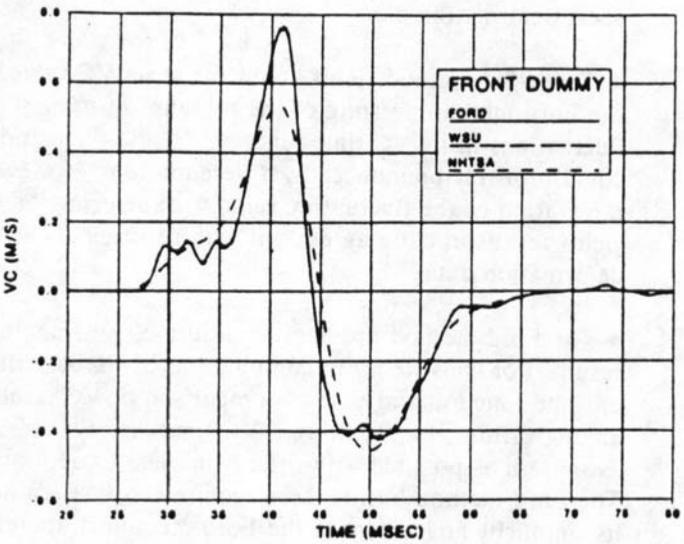


Figure 12: Comparisons of VC results among WSU, NHTSA, and Ford methods - Front seated dummy upper rib

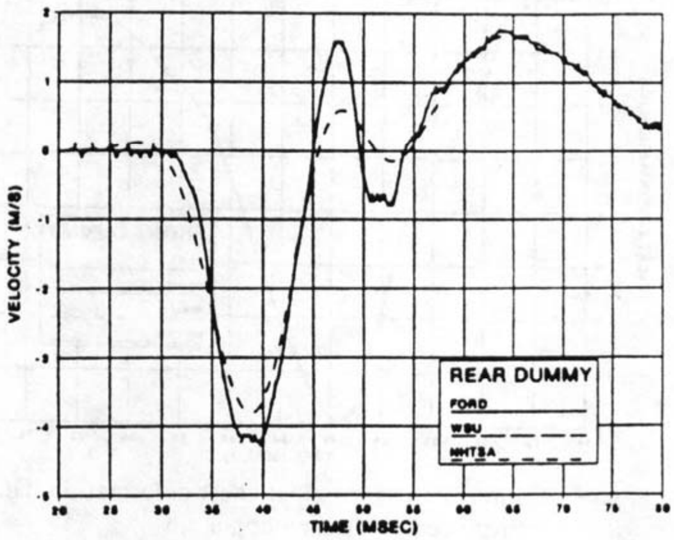


Figure 15: Comparisons of velocities of deformation among WSU, NHTSA and Ford methods - Rear seated dummy upper rib

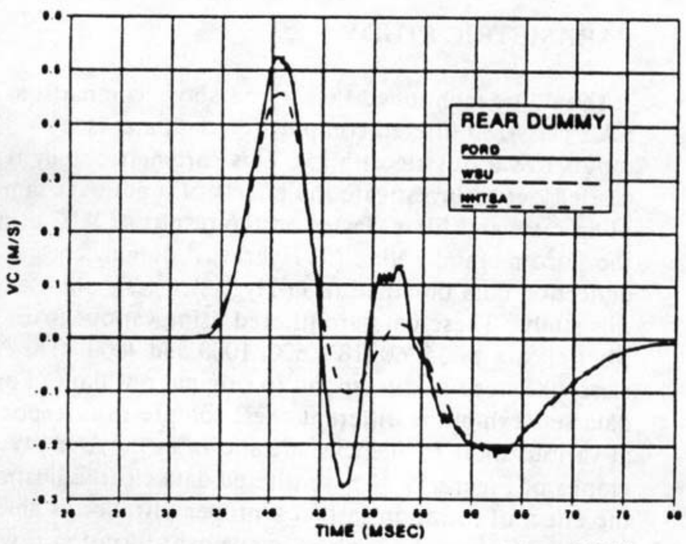


Figure 13: Comparisons of VC results among WSU, NHTSA, and Ford method - Rear seated dummy upper rib

Next, comparisons of the "integrated" and original chest deformation data are shown in Figures 16 through 18. In both the WSU and Ford methods, the "integrated" chest deformation reverted back to the original chest deformation data, indicating no significant "loss of information" in the process. The NHTSA method, on the other hand, yields significant discrepancies between the "integrated" chest data and the original chest data, thus suggesting inaccuracy in its VC algorithm.

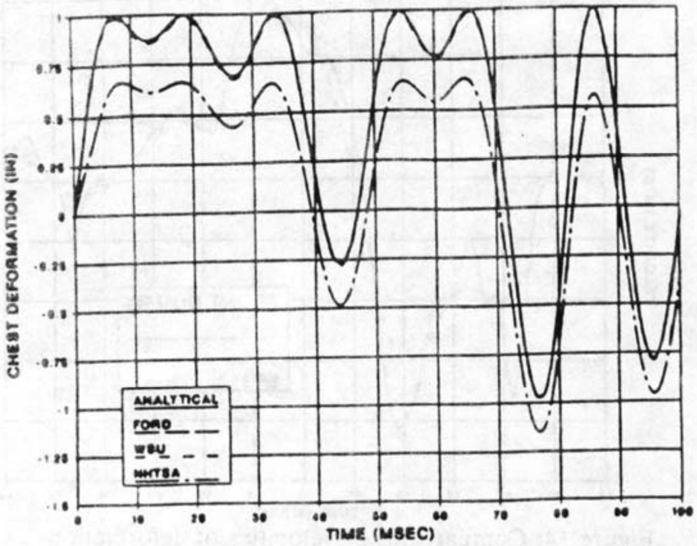


Figure 16: Integrated vs. original "chest deformation" data (analytically generated hypothetical data)

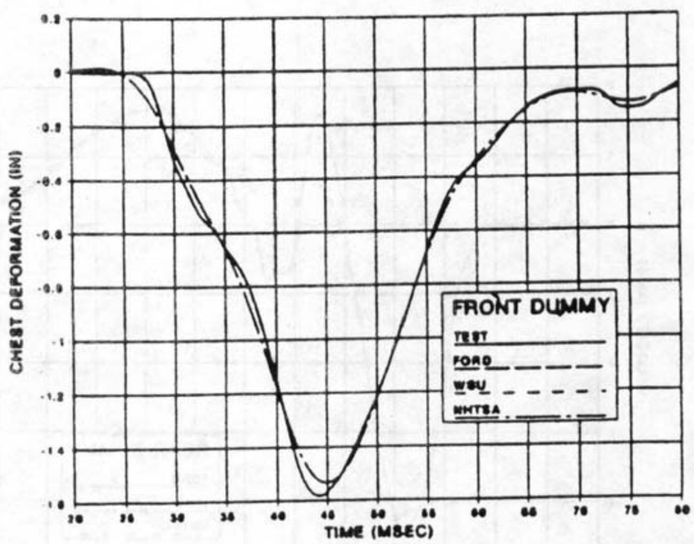


Figure 17: Integrated vs. original chest deformation data - Front seated dummy upper rib

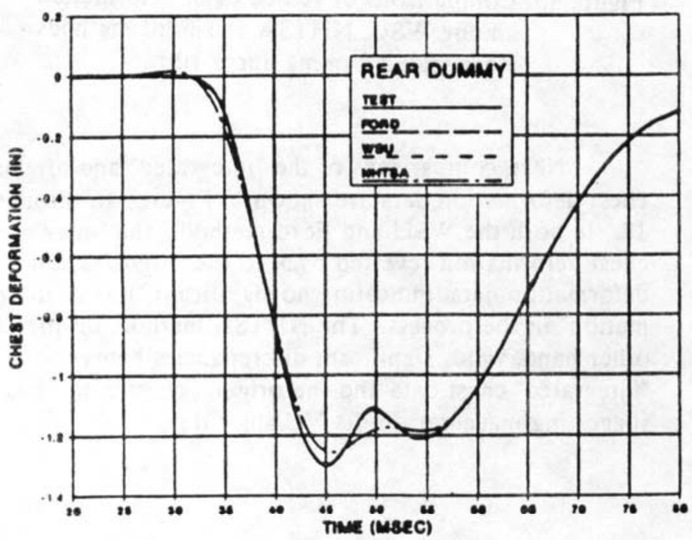


Figure 18: Integrated vs. original chest deformation data - Rear seated dummy upper rib

Based on the results and discussions presented above, the following observations are made:

- VC results depend on the scheme used in the computational process, which normally involves filtration and differentiation.

- VC results are also influenced by the "smoothness" of the input data. A "noisy" or highly oscillatory input data would induce great fluctuations in the derived velocity of deformation output. Different smoothing techniques are employed among the schemes studied.

- NHTSA uses a 4-th degree interpolating polynomial, WSU uses Lagrange's polynomial of degree 2, while Ford uses least squared parabolic curve fit.

- The NHTSA method yields the lowest VC value. Its velocity of deformation, upon integration, does not yield accurate chest deformation comparable to the original chest deformation data.

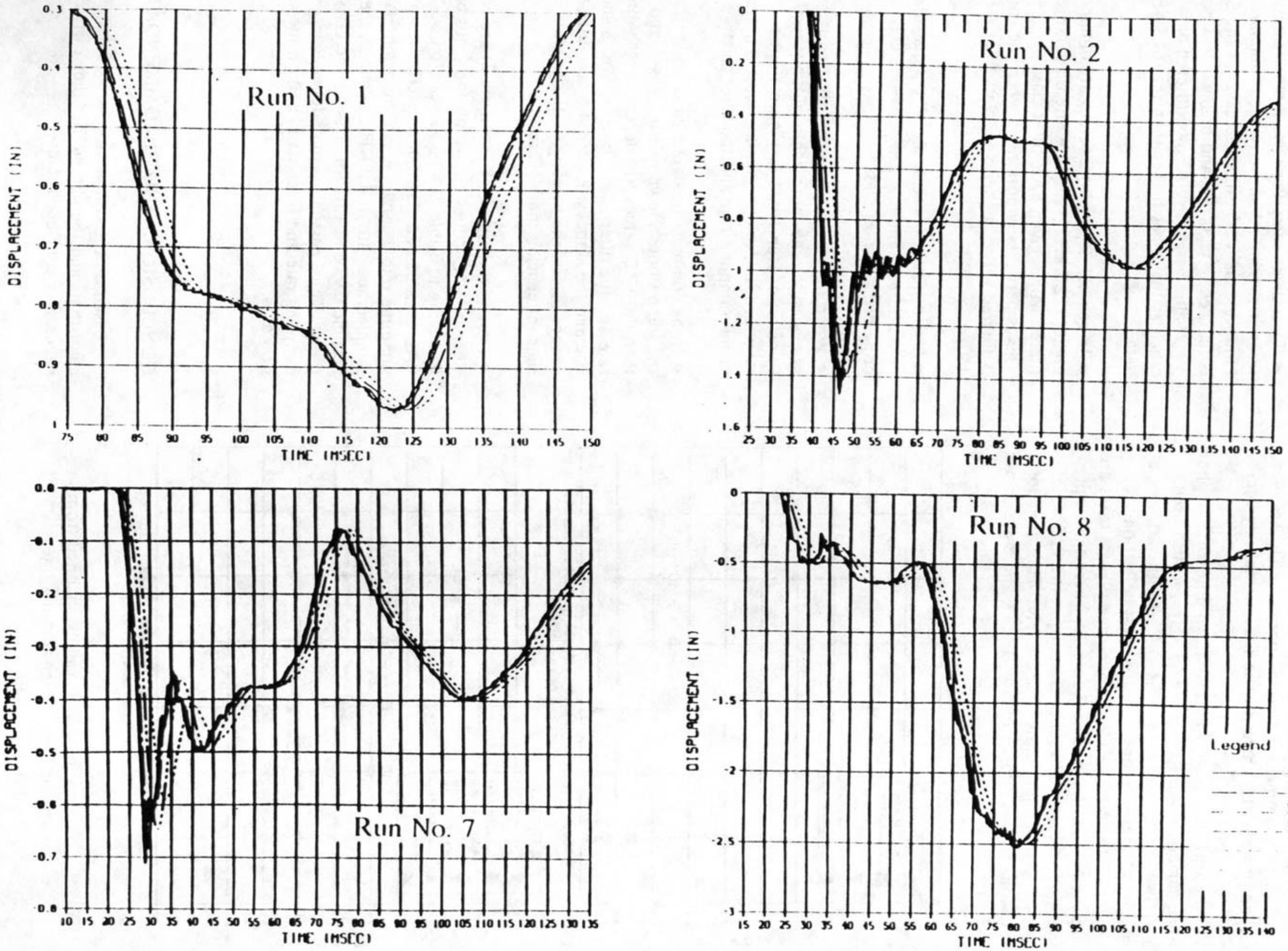
- The WSU method yields about the same VC value as the Ford method, in spite of the presence of some slight fluctuations in its VC time function. These fluctuations could probably be induced by differentiation. However, integration of the fluctuating velocity of deformation data yields results in close agreement with its original chest deformation data.

- The Ford method provides an accurate and smooth VC result. For consistency in computation of viscous criterion time function and ease of comparison of VC results among various test facilities, a VC time history should be as smooth as possible with little or no loss of accuracy. The Ford method fulfills these requirements. Because of its simplicity and accuracy, the Ford method is, therefore, recommended for use as in-house V*C computational algorithm.

PARAMETRIC STUDY

It should be mentioned that in the above comparisons, SAE class 180 filtered compression data are used as inputs to various algorithms. This parametric study is carried out to investigate the effects of input data sampling rates and filter classes on the results of V*C using the Ford method. Nine (9) Hybrid III dummy chest deflection data obtained from Hyge sled tests are used in this study. These data are filtered using various SAE filter classes of 35, 60, 180, 600, 1000 and 4000. The class 4000 results correspond to original raw data. Four data sets exhibiting different chest compression responses at various filter frequencies are shown in the four (4) graphs of Figure 19. These filtered data clearly illustrate the effect of filtration in that a proper filtration is able to eliminate/reduce the "noises", while over-filtration may

Figure 19: Input chest deformation data for parametric study



result in the "loss" of relevant information or in data "time-shift". It is seen that the data filtered at SAE 600, 1000, and 4000 class filters are close to each other. A class filter lower than the SAE 600 will shift the original data and alter its results. The data filtered with SAE class 60, for example, resulted in approximately 2.5 milli-seconds time shift with respect to the original raw data.

In addition to SAE filter class, two different sampling rates, namely, at 4.0 KHz and 12.5 kHz, are also used. With two sampling rates and six different filter classes, a total of 12 computations for each chest deflection are obtained. The V*C results for the nine (9) test cases are tabulated in Table 2 and in Figure 20, where the empty and solid symbols represent results from the 12.5 KHz and 4.0 KHz sampling rate, respectively. Time functions of viscous criterion for Run Nos. 1, 2, 7, and 8 are shown in Figure 21.

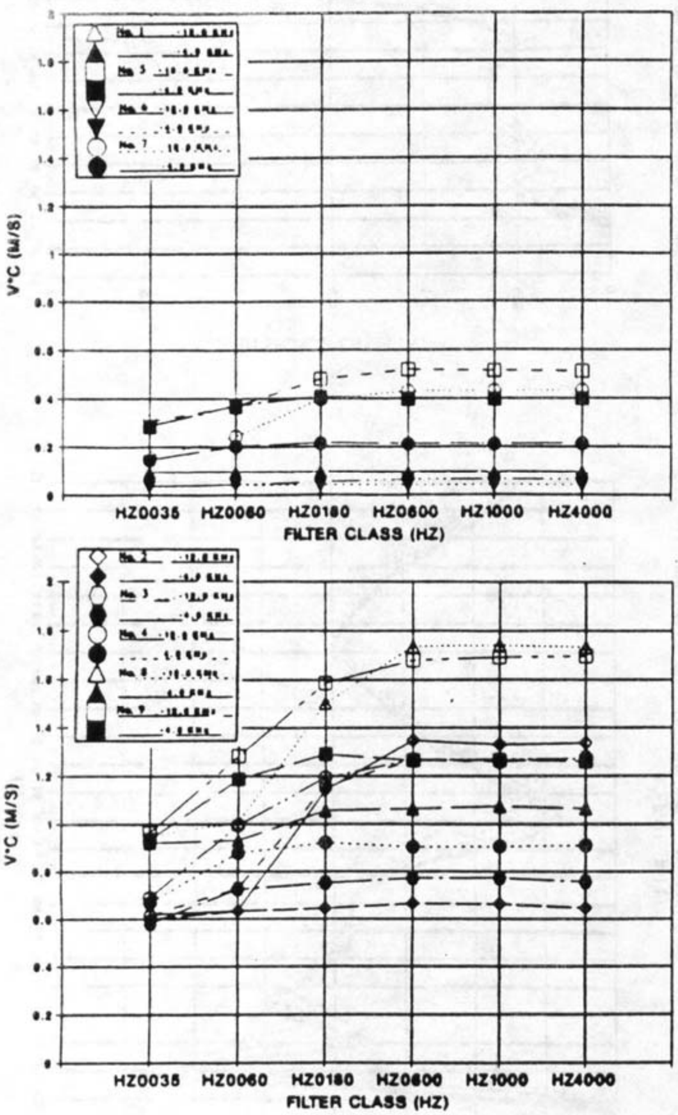


Figure 20: Comparison of V*C values obtained from 4.0 kHz and 12.5 kHz sampling rates as a function of filter class

In examining the results shown in Table 2 and Figures 20 and 21, the following observations are made:

- For a given sampling rate, compression data from SAE filter class 600 and above result in similar V*C values. However, the V*C value decreases as the SAE filter class is reduced to class 180 and below. It is noted that the V*C value based on SAE 600 filtered data can be as much as two times higher than that of SAE 60 filtered data.

- In general, larger V*C values are obtained from the higher (12.5 kHz) sampling rate on compression data filered with a given SAE filter class.
This is particularly noticeable when the compression data is filtered with a higher SAE class filter (above class 180).

- The disparity between the V*C values derived from two different sampling rate data sets decreases with lowering of SAE filter class.

- When the rate of chest compression is more gradual, as evident by the more gentle slope (or instantaneous velocity) of Run No. 1 in Figure 19, the V*C values as tabulated in Table 2 remain almost the same regardless of the sampling rate and the filter class.

- If the compression data have a rapid time rise, such as the steep slopes shown in Run Nos. 2 and 7 of Figure 19, then the V*C values will depend largely on the sampling rate and the filter class. In Run Nos. 2 and 7, the time rise and the slopes are altered by the filtration. This change affects the velocity of deformation calculations, thus influencing the V*C results.

- Results of Run No. 8 in Figure 21 are note worth since its V*C values are within the 1 m/s borderline. Referring to Table 2, V*C values are 0.95 and 1.01 for SAE class 35 and class 60, respectively, when a 12.5 KHz sampling rate is used. When the compression data are sampled at a rate of 4.0 KHz, however, the V*C values become 0.93 and 1.05 for class 60 and class 180, respectively. Thus, pass/fail verdict depends largely upon the sampling rate and filter class used on the input compression data.

CONCLUSIONS AND RECOMMENDATIONS

Based on the comparison of V*C computational algorithms and the parametric study carried out in this paper, it is concluded that:

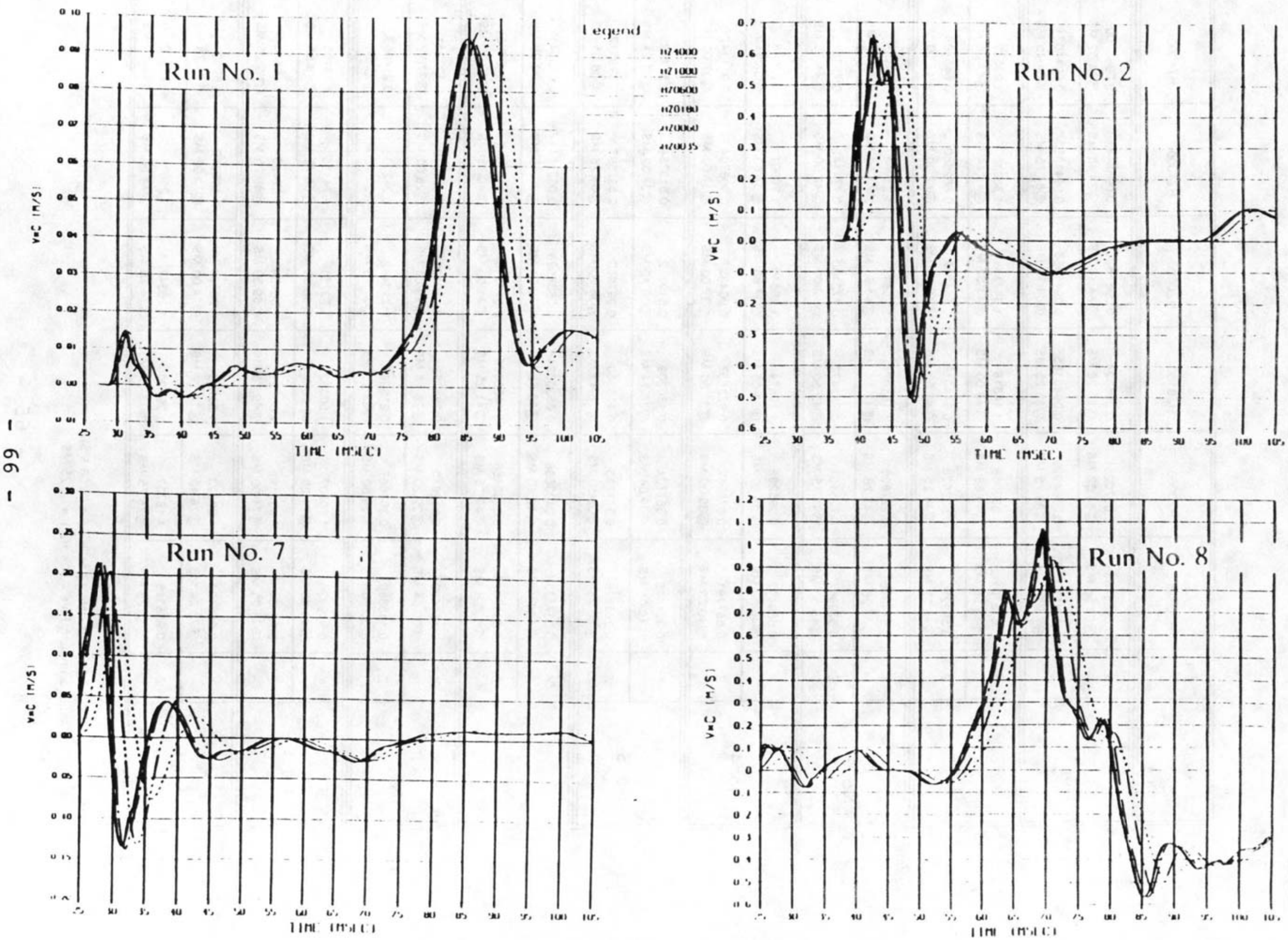
Table 2

Summary of V*C Results from Parametric Study
- variations of sampling rate and SAE filter class -

INPUT RUN #	S R Y/Z	HZ0035	HZ0060	HZ0180	HZ0600	HZ1000	HZ4000
No. 1	Y	0.0958469 @88.56 MS	0.0970261 @86.32 MS	0.096624 @85.28 MS	0.0968830 @84.48 MS	0.0966481 @84.48 MS	0.0963700 @84.32 MS
	Z	0.0945535 @88.50 MS	0.0964929 @86.75 MS	0.0943165 @85.25 MS	0.0941956 @84.75 MS	0.0941353 @84.75 MS	0.0944071 @84.75 MS
No. 2	Y	0.618701 @46.56 MS	0.633068 @44.88 MS	1.14318 @42.00 MS	1.34714 @41.52 MS	1.33010 @41.44 MS	1.33502 @41.36 MS
	Z	0.599290 @46.25 MS	0.632628 @44.25 MS	0.644016 @42.50 MS	0.664567 @42.00 MS	0.662680 @42.00 MS	0.646808 @42.00 MS
No. 3	Y	0.614340 @45.36 MS	0.727836 @43.28 MS	1.16107 @42.24 MS	1.26611 @41.68 MS	1.25988 @41.60 MS	1.27435 @41.52 MS
	Z	0.579967 @45.50 MS	0.725461 @43.75 MS	0.752477 @42.50 MS	0.773450 @42.00 MS	0.774142 @42.00 MS	0.757873 @41.75 MS
No. 4	Y	0.689192 @40.08 MS	0.995298 @38.80 MS	1.19474 @38.08 MS	1.26848 @37.68 MS	1.26901 @37.60 MS	1.27046 @37.44 MS
	Z	0.667491 @40.25 MS	0.878962 @39.00 MS	0.922657 @37.50 MS	0.904327 @37.00 MS	0.906704 @37.00 MS	0.911142 @37.00 MS
No. 5	Y	0.304486 @40.08 MS	0.367734 @39.04 MS	0.480209 @36.24 MS	0.519112 @38.40 MS	0.513784 @38.32 MS	0.511129 @38.24 MS
	Z	0.285876 @40.25 MS	0.371713 @38.50 MS	0.408360 @36.75 MS	0.397960 @36.50 MS	0.397597 @36.25 MS	0.399712 @36.25 MS
No. 6	Y	0.0371338 @100.7 MS	0.0433606 @42.40 MS	0.0530624 @30.56 MS	0.0638628 @30.24 MS	0.0631841 @30.16 MS	0.0635412 @30.08 MS
	Z	0.0367628 @100.8 MS	0.0430156 @42.75 MS	0.0405678 @41.25 MS	0.0405167 @41.00 MS	0.0405042 @40.75 MS	0.0407830 @40.50 MS
No. 7	Y	0.151680 @30.64 MS	0.242613 @29.20 MS	0.398759 @28.48 MS	0.430138 @28.08 MS	0.431519 @28.00 MS	0.433351 @27.92 MS
	Z	0.145880 @30.50 MS	0.203867 @29.50 MS	0.215288 @28.25 MS	0.213482 @27.75 MS	0.212138 @27.75 MS	0.214965 @27.50 MS
No. 8	Y	0.949920 @71.60 MS	1.00807 @71.28 MS	1.50362 69.28 MS	1.73751 @68.80 MS	1.74155 @68.72 MS	1.73295 @68.56 MS
	Z	0.921541 @71.25 MS	0.932199 @71.00 MS	1.05721 @69.75 MS	1.06439 @69.50 MS	1.07423 @69.25 MS	1.06506 @69.25 MS
No. 9	Y	0.965420 @78.24 MS	1.28323 @76.40 MS	1.58729 @74.72 MS	1.68098 @74.00 MS	1.692350 @73.92 MS	1.69631 @73.76 MS
	Z	0.936315 @78.25 MS	1.18707 @76.75 MS	1.29120 @75.25 MS	1.26547 @74.75 MS	1.26624 @74.50 MS	1.25972 @74.50 MS

Note 1. SR-Y: Input Sampling Rate 12.5K HZ (i.e., 0.08 MS)
2. SR-Z: Input Sampling Rate 4.00K HZ (i.e. 0.25 MS)
3. V*C in M/S

Figure 21: Time functions of V*C for Run no. 1, 2, 7, and 8



• Results of V*C depend on (1) the sampling rate and filter class of input data, (2) technique used in the differentiation, and (3) computation process/procedure used in an algorithm.

• Since various algorithms/procedures yield different V*C values, which is critical in determining the dummy response to pass/fail the viscous criterion, it is recommended that the computation scheme/process for calculation of V*C need to be standardized among the biomechanics research community, automotive industry and government regulatory agency.

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REFERENCES

1. ISO/TC22/SC12/WG5 - "Anthropomorphic Test Devices". Resolution agreed to at the 24th Meeting , Orlando, Florida, Oct. 31 - Nov. 1, 1990.

2. Lau, I. V. and D. C. Viano, "The Viscous Criterion-Based and Applications of an Injury Severity Index for Soft Tissue", Proceedings of the Thirtieth Stapp Car Crash Conference, held in San Diego, California, Oct. 27-29, 1986. SAE Paper No. 861882.

3. Canahan, B., H. A. Luther, and J. O. Wilkes, "Applied Numerical Methods", John Wiley & Son, Inc. 1969, pp. 128.

4. Ibid pp. 27.

5. Chou, C. C. and Y. S. Lin, "A Computational Technique for Differentiation of Film Analysis Data of Vehicle Barrier Crash Tests", P&MES Technical Report No. EM-91-01, 1991.

DISCUSSION

PAPERR: **An Evaluation of Various Viscous Criterion Computational Algorithms**

PRESENTER: Clifford Chou

OTHER AUTHORS: Y. S. Lin, G. G. Lim

QUESTION: Rolf Eppinger, NHTSA

If the original correlation by mechanical correlation between VC and the injury was established off the film data which you could possibly say was a thousand frames per second, and if you believe that it was an appropriate nyquist criteria, that information could only contain a maximum of 500 hertz, and if it was done properly, maybe 250 hertz in the displacement, what relevance does all this exercise you do have back to the basic fundamental bio-mechanical data base and its correlation to injury?

ANSWER: Well, we didn't go back to the qualities of fundamental injury criteria or what kind of data here because we don't have the data to start with. Most of the data we study here from the recommendation from the dummy, these are from SID or from Hybrid III. Now the question would be either you go back to look at the original data, go back to study those responses, what kind of frequency response from those data, and you try to establish what kind of a correlation. You have to determine what kind of frequency you have to use in computation of those averages.

Q: But at this point, you have no justification to go up to four kilahertz or twelve kilahertz if you know the basic data was obtained from film data. So, I don't understand the relevance between the high, even examining going up to those high frequency domains, rather than remaining down at 500 hertz or lower.

A: Yes. I think all the information there is based on the calculations; if you go back to the internal data and you are to modify a factor, say 1.3 something based on the number I have in that paper, then to correlate it, the internal measurement there, I don't have enough data to get kind of an assessment, but that type of assessment can be done.

Q: Guy Nusholtz, Chrysler Corporation

I have several questions and I'll go through them. Do you have an explanation of why the NHTSA routine, when you integrate back, is so far off in displacement? That's the first question. The second one is there is another method of obtaining the viscous criteria which requires the use of both accelerometers and displacement transducers. You can integrate the acceleration and adaptably change the gain so that its double integration matches the displacement from a displacement transducer given the error on the displacement transducer. That effectively becomes your differentiation routine and that gets rid of a lot of the problems with different sampling rates, high frequency and amplification of the noise by differentiation. In the last one, were you just looking at half of the chest width?

A: Yes. For the SID dummy, we use the half chest width. For the frontal, we use a four. We use a numberization factor from GM, the number we use in the numberization. In terms of the expiration data, I think we are looking into it but I don't have any result to show you.

Q: Do you have an explanation for why the NHTSA data is so far along?

A: The NHTSA data is due to all the filtering to start with. I think if you filter the chest information data where (is) you filter the differentiation velocity data too. The combination will give you less shift.

Q: That shouldn't have as much effect as you're showing on the slides. There's gotta be something else hidden in there.

A: Yes.

Q: OK. Thank you.

Q: Don Friedman, Liability Research

I realize that this kind of concern is sensitive to regulatory process but I just wanted to say that in studying a variety of real world accidents, like some ten involving frontal impact in which there were internal injuries due to chest trauma, what we find is that there is a clear result from VC because the product peaks very quickly when you get, for instance, column binding or any kind of lack of stroking to the full extent that's possible and so we see VC's that come out to be two or three, which correspond to people dying or getting aortic separation. The point is that in terms of sensitivity of the model as soon as you allow the stroking, the numbers drop by a factor of three. So that, if you think of a sense of the power of the VC, it is a way of showing what's failing more than it is to show how close you can come to optimize the design of the product to meet the criteria.

A: Yes. I think it is possible because it is dependent on two quantities. The velocity as well as the compression and you find out based on some of the studies; if you go back to a paper by J. T. Weir from GM you find out that the maximum VC curve, not necessarily the maximum velocity or maximum compression, is somewhere in between the combination and you can plot the velocity as a function of compression and the VC has a parabolic curve, the maximum parabolic curve tangent to the velocity compression. That is very interesting. We can do a different study there.

Q: Keith Friedman, Friedman Research

What was the magnitude of the difference for a given set of sampling rates and filtering between the various algorithms for the peak value? That is, what kind of variation is that?

A: It depends on the curve. It can be twice as much or 60%; something like that.

Q: A factor of two?

A: A factor of two, yes.

Q: And the maximum VC?

A: Yes. From the 4,000 hertz data to about 180 hertz data.

Q: For a fixed sampling rate and filter, what was that variation and the maximum negative?

A: I think that you can get as high as about 30%, something like that.

Q: Joe Balser, General Motors
You talked about the algorithm used by General Motors at the beginning of your talk, but you didn't use their technique in your analysis.

A: No, because we don't have a computer program available so we don't want to generate our own computer output for their algorithm.

Q: I see, thank you.